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Further Studies of Aircraft Disinsection and Odor Characteristics of Aerosols Containing Resmethrin and *d-trans*-resmethrin[*1]. W. N. SULLIVAN[*2], A. N. HEWING[*2], M. S. SCHECHTER[*2], J. U. McGUIRE[*3], R. M. WATERS[*2], and E. S. FIELDS[*2] (Entomology Research Division, Agr. Res. Serv., US Department of Agriculture[*2], and Biometrical Services Staff, Agr. Res. Serv., US Department of Agriculture[*3], Beltsville, Md. 20705, USA.) Received November 12, 1974. *Botyu-Kagaku* 40, 5, 1975.

2. Resmethrin, *d-trans*-resmethrin 含有噴霧剤の航空機内における殺虫効果と残留臭気について[1]

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WHO から航空機内での殺虫剤噴霧の効力と使用後の乗客，乗員に与える影響について調査を依頼された．この目的に，resmethrin と *d-trans*-resmethrin の殺虫効果が評価されたが使用後に悪臭の残るという苦情があり，これを軽減するために，有効成分の純度の高いものを製造してもらい，さらにテストを行なった．

精製 resmethrin と90.2% *d-trans*-resmethrin を用いてジェット機内の閉塞空調条件下で殺虫テストを行なった．同様なテストは，長距離飛行中でも行ない，その製剤の使用で乗客が不快な匂いを感ずるかどうかを，噴霧前後にアンケートに回答してもらうことで調べた．石油系溶剤を含有しない噴射剤 P11 : P12 (1 : 1) だけの使用で，5 g/1000 ft³ のスプレーが，イエバエ，カの駆除に効果があり，悪臭を残すこともなかった．

During 1971 the World Health Organization (WHO) conducted worldwide experiments with aerosols for the disinsection of aircraft at "blocks-away" (Sullivan *et al.*, 1972)[1)]. The results indicated that an aerosol containing 2% resmethrin (NRDC-104; SBP-1382) in propellants 11 and 12 (50:50) without kerosene was effective and was accepted favorably by the passengers;an aerosol containing *d-trans*-resmethrin (bioresmethrin; NRDC-107) was equally effective but was unfavorably received by the passengers. The subsequent investigation of the odors revealed that the residues from repeated application of either technical resmethrin or *d-trans*-resmethrin on glass plates exposed to direct sunshine for 1 to 3 days had an unpleasant musty or urine-like odor due to photodecomposition. A similar odor was produced in treated, closed rooms with sunshine filtering through windows and/or lighted with fluorescent tubes. The World Health Organization therefore requested the US Department of Agriculture to investigate the odor and possible means of reducing or eliminating it.

The manufacturers have made intensive efforts to refine their product and to add antioxidants to the mixture. The result was a technical product with a greatly improved odor as deter-

*1 This paper reports the results of research only. Mention of a pesticide or a commercial product in this paper does not constitute a recommendation or an endorsement of this product by the US Department of Agriculture.

mined by panels of people who "sniffed" glass plates that had been repeatedly treated and then exposed to sunlight. The present paper reports further tests of the odor and effectiveness of these refined products when they were applied in air-conditioned rooms and during regular flights of jet aircraft. These studies were a cooperative effort of the following groups: The Entomology Research Division and the Biometrical Services Staff, Agricultural Research Service, US Department of Agriculture, Beltsville, Md.; and the Military Airlift Command (MAC), US Air Force, Scott Air Force Base, Illinois, through the Armed Forces Pest Control Board, Department of Defense.

Materials and Methods

The 3 test rooms were air conditioned (32.98 to 71.96 m^3, i.e., 1164 to 2540 ft^3) and continuously and brightly illuminated with fluorescent lights; one room (sprayed with *d-trans*-resmethrin) had a window with a southern exposure.

The tests in aircraft were made in two C-141 Lockheed jet passenger-cargo aircraft on regular missions. The aircraft had a volume of 396.6 m^3, i.e., 14000 ft^3, crew of 10, from 28 to 72 seated passengers, and pallets containing cargo in the rear. Air exchange at blocks-away occurs once every 5 minutes.

Two lots of resmethrin supplied by S. B. Penick & Co., New York, USA, were used in the trials, a purified technical grade (Lot 6992-RN RF-10), and a premium grade of resmethrin (Lot 6987-RM RF-50). The *d-trans*-resmethrin was a technical grade supplied by Cooper France S. A., through the courtesy of Cooper, McDougall & Robertson, Berkhamstead, UK, and was considered by them to have greater biological activity and to be more representative of the current production than earlier samples; it contained 91.5% total isomers by weight, 1.3% *cis* isomer, and 90.2% *d-trans*-resmethrin.

Research by Schechter *et al.* (1949)[2] and Elliott *et al.* (1967)[3] resulted in the discovery of synthetic pyrethroids effective against insects of medical and agricultural importance (Elliott 1967[3]; Fales *et al.* 1968[4]; Brooks 1968[5]; Okuna 1969[6]; and Brooks *et al.* 1971[7]).

In our experiments, the synthetic pyrethroids were formulated as aerosols without auxiliary solvents such as petroleum distillates (Schechter *et al.* 1961)[8]. The propellants 11±12 (50:50) were the only other ingredients except for one formulation which contained P11+P12 (30:70). The test formulations were therefore:

1. 1.20% resmethrin (1.34% of 90.0% Grade RF-10) 98.66% propellants 11±12 (50:50)
2. 1.20% resmethrin (1.34% of 90.0% Grade RF-10) 98.66% propellants 11+12 (30:70)
3. 2.00% resmethrin (Lot No. 6987-RM, Premium Grade RF-50) 97.72% propellants 11+12 (50:50)
4. 1.20% *d-trans*-resmethrin (1.33% of 90.2% technical grade) 98.67% propellants 11+12 (50:50).

All aerosols were packaged in Beltsville, Md., in 12-oz (339.6 g) cans equipped with valves. The flow rate was approximately 1.1 g/second; the particle size of the 2 and 1.2% resmethrin aerosols were 12.5 and 10 microns mass median diameter, respectively.

Insects

Culex quinquefasciatus Say were selected as one of the test insects because they occur in nature in the United States, Hawaii, and American Samoa (stops on the flights of the test aircraft). Before the test flights, they were aspirated from stock cages into 1/2-pint (236.6 cc) cardboard ice cream cartons (ends replaced by 16-mesh wire screen). House flies, *Musca domestica* L., CSMA 1948 strain (susceptible), similarly caged, were the other test species; however, in 2 instances, house flies were also liberated in the aircraft.

Experimental procedure

The test rooms were treated with double doses of the aerosols each day (6 to 10 g of aerosol total per 1000 ft^3 (28.3 m^3) per day) for 3 successive days. Just before treatment on the 1st, 2nd and 3rd days and also on the 4th day (no treatment) the test panelists (13-22 people) characterized the odors of the 3 test rooms (A, B, & C) at 5-minute intervals in this order on successive days, A, B, C; B, C, A; C, A, B; A, B, C. The panelists were a mixture of male & female scientists & secretaries with some changes in

Fig. 1. Passenger questionnaire.

DATE: ______________ TEST NO. ______________ AREA TREATED: ______________

THE WORLD HEALTH ORGANIZATION
THE U.S. DEPARTMENT OF AGRICULTURE
THE U.S. DEPARTMENT OF DEFENSE

On entering the aircraft, the cabin air was:

- Very pleasant: ☐
- Vaguely pleasant: ☐
- Undecided: ☐
- Slightly unpleasant: ☐
- Decidedly unpleasant: ☐
- Other observations: ______________________________

One-half hour before landing, the cabin air was:

- Very pleasant: ☐
- Vaguely pleasant: ☐
- Undecided: ☐
- Slightly unpleasant: ☐
- Decidedly unpleasant: ☐
- Other observations: ______________________________

personnel from day to day.

For the tests in the aircraft, cages of mosquitoes and house flies were placed at 8-10 test stations in the aircraft (selected as likely hiding places for insects) and the control insects were placed in plastic bags. Then as soon as the passengers boarded, questionnaires relative to the odor in the aircraft were distributed (see Fig. 1), the purposes of the experiment were explained, and the first half of the questionnaire was filled out. Then the jet engines were started. At "blocks-away" the test aerosol was applied by the operator who walked through the aircraft releasing the aerosol at a target dosage of 5 g/1000 ft^3 in a slightly upward direction with a side to side motion. The test insects were collected, examined for half hour knockdown, and fed at the end of each flight. Mortality counts were made 6-24 hours later. The second half of the questionnaire was filled out by the passengers one half hour before landing. In some instances, the aircraft was also disinsected with the test aerosol before landing in compliance with US Air Force regulations; however, the test insects were secured in plastic bags and were not exposed to this second treatment.

Results

The characterization of odors of residual deposits of resmethrin and *d-trans*-resmethrin aerosols after repeated applications in the test rooms is given in Table 1. An analysis of this data by the non-parametric Kolmogorov-Smirnov test (Siegel 1956)[9] is presented in Table 2.

The effectiveness of the aerosols against mosquitoes and house flies when they were applied at blocks-away in regular flights of jet aircraft is given in Table 3. The passenger reactions to

Table 1. Characterization of odors from residual deposits of pyrethroid aerosols by panels of people.

	Dosage g/1000 ft³ 28.3 m³	Temp (°C)	No. of people in test	Very pleasant (2)	Vaguely pleasant (1)	Neither (0)	Slightly unpleasant (−1)	Unpleasant (−2)
			Percentage characterizing odors as					
			1.2% *d-trans*-Resmethrin, 2540 ft³ room (71.96 m³)					
Day 1-Pretest		N.A.	13	15.4	46.1	23.1	15.4	0.0
Day 1-Application	10							
Day 2	10	22	20	15.0	35.0	40.0	10.0	0.0
Day 3	10	23	20	25.0	50.0	20.0	5.0	0.0
Day 4		25	22	18.2	54.6	22.7	4.5	0.0
			2% Premium resmethrin (RF-50), 1164 ft³ room (32.98 m³)					
Day 1-Pretest		N.A.	13	7.7	15.4	30.8	38.4	7.7
Day 1-Application	6							
Day 2	6	29	20	15.0	10.0	30.0	40.0	5.0
Day 3	6	25	20	25.0	45.0	15.0	15.0	0.0
Day 4		26	22	13.6	27.3	22.7	36.4	0.0
			1.2% Resmethrin (RF-10), 1690 ft³ room (47.83 m³)					
Day 1-Pretest		N.A.	13	7.7	38.4	30.8	15.4	7.7
Day 1-Application	10							
Day 2	10	30	20	10.0	20.0	30.0	25.	15.0
Day 3	10	27	20	0.0	45.0	10.0	35.0	10.0
Day 4		29	22	9.1	22.7	27.3	31.8	9.1

Table 2. Analysis (Kolmogorov-Smirnov test) of the odor characteristics of residues from repeated applications of resmethrin and *d-trans*-resmethrin.

Day	Response classification	A (*d-trans*-resmethrin) Cumulative frequency	Cumulative proportion	B (Resmethrin—premium, RF 50) Cumulative frequency	Cumulative proportion	C (Resmethrin—technical, RF 10) Cumulative frequency	Cumulative proportion
1	−2	0	0.0	2	0.0952	3	0.15
(24 h)	−1	3	0.1364	10	0.4762	8	0.40
	0	11	0.5000	16	0.7619	14	0.70
	1	19	0.8636	18	0.8571	18	0.90
	2	22	1.0000	21	1.0000	20	1.00
2	−2	0	0	0	0	2	0.10
(48 h)	−1	1	0.0500	3	0.15	9	0.45
	0	5	0.2500	6	0.30	11	0.55
	1	15	0.7500	15	0.75	20	1.00
	2	20	1.00	20	1.00	20	1.00
3	−2	0	0	0	0	2	0.1053
(72 h)	−1	1	0.0455	8	0.3636	9	0.4737
	0	6	0.2727	13	0.5909	15	0.7895
	1	18	0.8182	19	0.8636	17	0.8947
	2	22	1.0000	22	1.0000	19	1.0000
1A v 2A		(0.42)	nd	1B v 2B	(0.425) nd	1C v 2C	(0.43) nd
1A v 3A		(0.41)	nd	1B v 3B	(0.415) nd	1C v 3C	(0.436) nd
2A v 3A		(0.42)	nd	2B v 3B	(0.42) nd	2C v 3C	(0.436) nd
1A v 1B		(0.415)	nd	2A v 2B	(0.43) nd	3A v 3B	(0.42) nd
1A v 1C		(0.42)	nd	2A v 2C	(0.43) nd	3A v 3C	(0.426) .5168
1B v 1C		(0.425)	nd	2B v 2C	(0.43) nd	3B v 3C	(0.426) nd

Table 3. The effectiveness against mosquitoes and house flies of resmethrin (RF 10) and *d-trans*-resmethrin aerosols applied at blocks-away to disinsect C-141 jet passenger-cargo aircraft (396.6 m^3, 14,000 ft^3)

Test no.	Flight and date	Aircraft Temp (°C)	Insecticidal aerosol	Dosage (g/1000 ft^3)	*Culex quinquefasciatus* No. insects	*Culex quinquefasciatus* KD: % 1/2 h	*Culex quinquefasciatus* Mortality: % 6-24 h	*Musca domestica* No. insects	*Musca domestica* KD: % 1/2 h	*Musca domestica* Mortality: % 6-24 h
1 A	Scott Air Force Base, Ill., to Hill AFB, Utah, USA (2/27/72)	21	1.2% *d-trans*-resmethrin in P11-P12 (50:50)	5.0[a]	112	100	100	29	80	100
1 B	Hill AFB, Utah, to McCord AFB, Washington State, USA (2/27/72)	23	1.2% *d-trans*-resmethrin in P11-P12 (50:50)	9.0[a,c]						
1 C	McCord AFB, Washington State, to Travis AFB, Calif., USA (2/27/72)	23	1.2% *d-trans*-resmethrin in P11-P12 (50:50)	5.2[a]				85	100	100
2 D	Sydney, Australia, to Pago Pago, American Samoa (3/3/72)		1.2% resmethrin in P11-P12 (50:50)	9.7[b,d]						
2 E	Pago Pago to Hickam AFB Hawaii, USA (3/3/72)		1.2% resmethrin in P11-P12 (50:50)	9.7[b,d]						
2 F	Hickam AFB, Hawaii, to Travis AFB, Calif. (3/4/72)	22	2.0% resmethrin in P11-P12 (50:50)	6.9[a]				427	100	100
	Controls-Insects in closed plastic bags during test period									
1 A	Scott AFB to Hill AFB (2/27/72)	21			11	0	0	26	0	27
1 C	McCord AFB to Travis AFB (2/27/72)	23			12	0	8	35	0	12
1 D	Travis AFB, Calif., to McGuire AFB, New Jersey, USA (2/28/72)		1.2% *d-trans*-resmethrin in P11-P12 (50:50)							

2 A	Travis AFB, Calif., to Hickam AFB, Hawaii, USA (2/29/72)	22	1.2% resmethrin in P11-P12 (30:70)	19.2[a,d]	72	100	100			
2 B	Hickam AFB, Hawaii, to Pago Pago, American Samoa (3/1/72)	26	1.2% resmethrin in P11-P12 (50:50)	5.0[b]	131	100	100	720	100	84
2 C	Pago Pago to Sydney (Richmond), Australia (3/1/72)		1.2% resmethrin in P11-P12 (50:50)	7.2[b]						
2 A	Travis AFB to Hickam AFB (2/29/72)	22			16	0	0			
2 B	Hickam AFB to Pago Pago (3/1/72)	26			24	25	25	48	0	0
2 F	Hickam AFB to Travis AFB (3/4/72)	22						60	0	0

[a] Delivery rate x seconds sprayed.

[b] Actual; aerosol can weighed before and after using.

[c] Material sprayed for an additional time to give the equivalent deposit of a 2% treatment.

[d] Approximately 5 g aerosol/1000 ft^3 while insects were exposed; the additional dosage was delivered before landing to satisfy local quarantine requirements.

the odors in the cabins are given in Table 4.

Statistical analysis

The testing of the panel reactions to the three rooms was done in three steps.

(a) Step 1. The before-treatment data were tested against the after-treatment data by combining all after-treatment data and comparing the two distributions by the Kolgomorov-Smirnov non-parametric test; it was found that the after-treatment reactions differed from the pre-treatment.

(b) Step 2. The pre-treatment data were excluded. Three tests were made, the first treatment data against those of the second and third; and the second treatment data against the third. The results of days 1 and 2 against the third day were significant.

(c) Step 3. The data was separated into a material by period table (see table 2) and all pairwise tests made; this located the one significant comparison, a build-up of unpleasantness due to technical resmethrin over *d-trans*-resmethrin from the second to third periods*4.

The second analysis had to do with the response of passengers in the aircraft. However, the same rating scale was used as in the room tests. The data, as given in Table 4, were first combined into two sets that reflected responses before and after treatments and then compared by using the 2-sample Kolmogorov-Smirnov non-parametric test to determine whether the two samples have been drawn from the same population. The 2-tailed test was used because it is sensitive to such differences as location, dispersion, and skewness.

The before and after responses (disregarding materials) were

Response code	Before (B) (cumulative)	After (A) (cumulative)	(B-A) (difference)
−2	1	4	−3
−1	40	30	10
0	84	75	9
1	173	163	10
2	270	270	0

*4 The authors do not consider that this is serious. The room had water on the floor from a leaking pipe and was excessively warm the third day. These conditions probably affected the reaction adversely.

Then by the critical difference for 5% significance,

$$D=\left(1.36\sqrt{\frac{1}{270}+\frac{1}{270}}\right)(270)=(0.1171)(270)=31.6,$$

there was no difference since all computed differences were smaller than D.

Since we could not show a difference in the before and after responses, we tested the "after" responses to the materials alone.

With M_1 (*d-trans*-resmethrin) versus M_2 (resmethrin) the result was:

Response Code	Cumulative M_1	Cumulative M_2	Proportion M_1	Proportion M_2	Difference M_1-M_2
−2	1	3	.006	.03	
−1	21	9	.124	.09	
0	52	23	.306	.23	
1	121	42	.712	.42*	.292
2	170	100	1.000	1.00	

* Significant at the 5% level.

The critical difference, as a proportion, was 0.136; therefore, one difference was larger so we judged the two samples to be different. Also, when we combined the "before" and "after" data, the judgment did not change. The combined means were: M_1=.7647; M_2=.99; thus, M_2 (resmethrin) was preferred over M_1 (*d-trans*-resmethrin) though the two means fall in the positive interval 0, 1.

The mortality of the caged mosquitoes and house flies was 100% in all tests with the 1.2% concentration of *d-trans*-resmethrin aerosol. The released house flies (2 tests) that were recovered also were all dead. Also, all caged mosquitoes and house flies were killed with the 2.0% concentration of resmethrin, but the 1.2% concentration killed only 84% of the house flies in one test. The controls were satisfactory except for one instance where the mortality of the house flies was 27 percent.

Since the passenger reaction to repeated treatments of both resmethrin and *d-trans*-resmethrin was favorable and since the odor was not considered objectionable when the aircraft was disinsected at "blocks-away" either 2% resmethrin or 2% *d-trans*-resmethrin in P11+P12 (50:50) at a dosage of 5 g/1000 ft³ could be used as a standard aerosol treatment for disinsecting aircraft on international flights.

Table 4. The passenger reaction to the odors from resmethrin (RF-10) and *d-trans*-resmethrin in two C-141 jet passenger and cargo aircraft.

Test No.	Flight	Insecticidal Aerosol	Dosage g/1000 ft³	No. of people	Odor characterization, percent									
					Before spraying					1/2 Hr before landing				
					Very pleasant	Vaguely pleasant	Neither	Slightly unpleasant	Unpleasant	Very pleasant	Vaguely pleasant	Neither	Slightly unpleasant	Unpleasant
1 A	Scott-Hill	1.2% *d-trans*-resmethrin in P11+P12 (50:50)	5.0	63	11.1	38.1	22.2	27.0	1.6	19.1	46.0	20.6	14.3	0
1 B	Hill-McCord	1.2% *d-trans*-resmethrin in P11+P12 (50:50)	9.0	61	27.8	41.0	11.5	19.7	0	21.3	49.2	16.4	13.1	0
1 C	McCord-Travis	1.2% *d-trans*-resmethrin in P11+P12 (50:50)	5.2											
1 D	Travis-McGuire	1.2% *d-trans*-resmethrin in P11+P12 (50:50)		46	45.7	26.1	17.4	10.8	0	52.2	21.7	17.4	6.5	2.2
2 A	Travis-Hickam	1.2% resmethrin in P11+P12 (30:70)	19.2	28	67.9	14.3	17.8	0	0	71.4	10.7	14.3	3.6	0
2 B	Hickam-Pago Pago	1.2% resmethrin in P11+P12 (50:50)	5.0	25	48.0	40.0	8.0	4.0	0	56.0	24.0	12.0	0	8.0
2 C	Pago-Pago Sydney (Richmond)	1.2% resmethrin in P11+P12 (50:50)	7.2											
2 D	Sydney-Pago Pago	1.2% resmethrin in P11+P12 (50:50)	9.7	27	44.5	29.6	18.5	7.4	0	59.3	11.1	11.1	14.8	3.7
2 E	Pago Pago-Hickam	1.2% resmethrin in P11+P12 (50:50)	9.7											
2 F	Hickam-Travis	2.0% resmethrin in P11+P12 (50:50)	6.9	20	45.0	30.0	15.0	10.0	0	40.0	35.0	20.0	5.0	0

Summary

Further studies were made on the effectiveness of resmethrin (NRDC-104) and *d-trans*-resmethrin (NRDC-107) for disinsecting jet aircraft at "blocks-away". The same aircraft was disinsected with the same material at each leg of a long-distance flight, and passengers characterized the aircraft odors before and after treatment. Either 2% resmethrin or 2% *d-trans*-resmethrin in P11+P12 (50:50) at 5 g aerosol/1000 ft^3 (28.3 m^3) gave an excellent kill of mosquitoes and house flies. No odor buildup was observed.

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